Asymmetric Spokes: a demonstration of free-breathing pTX in the human torso at 7T

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Introduction:

In the recent past several publications have demonstrated parallel transmission (pTX) [1,2] for flip-angle homogenization at ultra-high field in the human brain [3, 4, among others]. For slice selective pTX applications, the popular "spokes" method is often used [5,3]. On conventional scanners asymmetric sinc-pulses, are commonly adopted to reduce the minimum echo time in fast slab-selective sequences such as the VIBE. To optimize the echo time for these clinically relevant sequences in the pTX framework, we introduce the asymmetric spoke (a-spoke) design. In addition, we present an optimized free-breathing B1-mapping procedure. The comprehensive method is demonstrated by homogenizing the flip-angle on a 6cm axial slab through the human torso at 7T using the 3DVIBE sequence.

Methods:

Experimental verification was performed on a Siemens 7T Magnetom scanner equipped with an 8-channel pTX-setup (Siemens, Erlangen, Germany). In this case an 8-element transceiver-array torso coil was used (**Fig. 1**). Transmit-sensitivity (B1) maps corresponding to each of the coil-elements were derived from a set of relative maps acquired using un-prepared Turbo-FLASH shots to minimize breathing motion artifacts (Inter Echo Time = 3.3ms, TE = 1.64ms, 40 slices, 64x64 matrix, 5mm-iso, nominal flip-angle = 3°, total acquisition time 18s). Two complementary absolute B1-maps, corresponding to the circularly polarized (CP) and gradient modes of the coil, were obtained using the DREAM sequence (TR = 5.6ms, TE1/TE2 = 2.04/3.06ms, 40 slices, 64x64 matrix, 5mm-iso, nominal flip-angle = 60°, total acquisition time 30s). Spoke pulses (time to bandwidth product = 8, symmetric sub-pulse duration 0.76ms, asymmetric sub-pulse duration 0.48ms) were designed using the spatial domain method [6] including variable exchange method [7]. Optimal k-space locations were found using a greedy algorithm [8]. For the a-spoke excitations, reflecting the even numbered sub-pulses in time minimized the cumulative pulse duration. The thus obtained a-spoke excitation (targeting a 9° FA) was inserted in to the 3DVIBE sequence (TR=30ms; TE = 2.9ms, 192 base matrix, 6cm slab thickness, 1.4mm-iso, 3 sub-pulses). To illustrate the difference in image quality 2DGRE images (TR = 20ms TE = 4ms, 256 matrix, 1.1mm iso) were obtained using both the CP-mode and a 3-spoke excitation. Informed consent was obtained from each of the volunteers, in accordance with the regulations of our institution. The forward power injected in to each of the individual coils was monitored in real time, and conservative RF-power limits were enforced.

Fig 1: Transmit-array coil used.

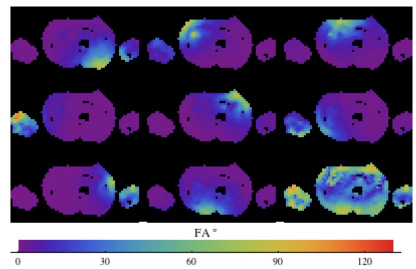

Fig 2: B1-maps corresponding to each of the individual coil-elements, measured in-vivo while breathing freely. In addition the CP-mode is shown in the lower right corner.

Results:

The DREAM sequence is "self-referenced" enabling free-breathing absolute B1-mapping. Combining the two complementary coil-modes reduces the bias otherwise introduced by low FA areas (**Fig. 2**, lower right corner). Exploiting the excellent motion robustness of the TFL sequence, qualitatively good B1-maps are obtained for each coil-element (**Fig. 2**). The comprehensive B1-mapping procedure can be performed in less than 4min while the volunteer breathes freely. The increased excitation fidelity provided by the spokes solution is shown **Fig. 3**. Compared to the conventional spokes solution, the total RF-pulse duration was reduced by from 2.8ms to 1.6ms (**Fig. 4**), while maintaining excellent excitation fidelity (**Fig. 5**).

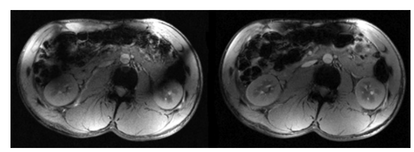

Fig 3: Axial slices obtained with the circularly polarized mode (left) and a conventional 3-spoke pulse (right).

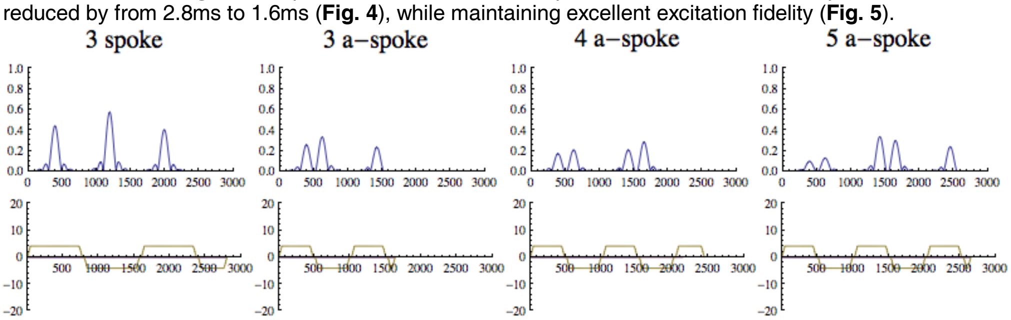

Fig 4: Example RF amplitude waveforms (top) and slice encoding gradients (bottom) for different spoke and a-spoke excitations. From left to right, conventional 3 spoke, 3 a-spoke, 4 a-spoke, and 5 a-spoke excitations. Note that, due to the refocusing gradient, the duration of the 4 a-spoke and the 5 a-spoke one are nearly identical.

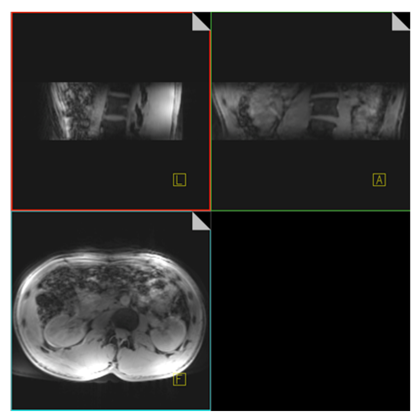

Fig 5: Three orthogonal plains trough a slab in the abdomen excited using 3 asymmetric-spokes. Note that the blurring visible in these images is due to breathing motion during the accusation (Cartesian 3DVIBE).

Discussion & conclusions:

We successfully demonstrated the potential of pTX to mitigate the strong B1-interference artifacts produced in the human torso at 7T. Moreover, we showed that the comprehensive protocol could be implemented without restrictions to the patients breathing pattern or time consuming gating techniques. Considering that many patients are incapable of holding their breath for a prolonged time, the ability for pTX to be incorporated in a free-breathing protocol dramatically increases its potential for clinical applications. Regarding the here introduced a-spokes design, one interesting property of the a-spoke design is that odd numbers of sub-pulses are highly favorable due to the reduced refocusing gradient duration (**Fig. 4**). Currently, initial experiments have started to explore radial sampling in the VIBE sequence to suppress the artifacts induced by breathing motion [9], and methods for in-vivo quantification of the obtained FA uniformity are under preparation.

References:

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